A REALISTIC APPROACH TO AIRCRAFT LIGHTNING PROTECTION

G. L. Weinstock
McDonnell Aircraft Company, McDonnell Douglas Corporation

ABSTRACT

Lightning protection for fighter aircraft is presently based on the requirements of MIL-B-5087 and refined by the recently issued MIL-STD-1757. These documents specify current and energy levels sufficient to cover greater than 99 percent of the cloud-to-ground strikes. These levels are applied to aircraft according to lightning strike zones established by attach point analysis and test. The application of these specifications to aircraft is made without consideration of mission, probability of strike occurrence, or penalties associated with protective designs. Data from recent in-flight test programs, a tabulation of aircraft strike rate per aircraft type, and an examination of strike damage records, all show that the requirements may be too stringent and that a revision to the method of applying lightning specifications to aircraft may be justified.

In conventional and V/STOL high-technology fighter aircraft, weight has a direct effect upon performance, combat effectiveness, losses, and life-cycle cost. Unnecessarily stringent lightning protection requirements can add weight out of proportion to the lightning risk. A systematic method of tailoring requirements to risk or damage probability is desirable to provide a more balanced protective design. This paper presents a probabilistic approach to the design of aircraft lightning protection which may be a useful method of avoiding conventional worst case design penalties.

THE PURPOSE OF THIS PAPER is to present a new approach to lightning protection for tactical military aircraft based upon realistic probabilities of strike parameters and damage.

In recent years, there has been an increased emphasis in providing lightning protection for tactical aircraft. New specifications of the lightning environment have been generated and some old specifications have been provided with expanded interpretations. These new lightning descriptions have generally been based upon compilations of cloud-to-ground strikes gathered by Stanford Research Institute under contract to McDonnell Douglas Astronautics and published in 1972[1]. Data on frequency of strikes to aircraft has been based primarily upon commercial airline experience. Recent information and an examination of old data strongly suggests that for tactical military aircraft, the lightning specification description, the current amplitudes, and the frequency of air strikes are overly severe.

BACKGROUND

Based upon the in-service records of the U.S. Navy on lightning strikes to aircraft[2], the actual strike frequency is lower by more than a factor of 10 than that used for design of lightning protection for recent aircraft. For example, the strike rate for fighter/attack type aircraft was less than one strike per 100,000 flight hours whereas, the rate used as a specification for protection design is on the order of one strike per 5,000 flight hours. This data clearly implies that the strike rate specification is overly severe.

APPROACH

A more quantitative definition of the "correct" specification can be made by applying statistical methods to the inflight strike data. Of primary interest is a definition of the probability distribution for strike frequency (i.e. strikes/flight hour) versus hours of flight. Alternatively, a definition of the average strike frequency, in terms of expected value and range, is a convenient parameter which serves the same purpose. That is, for the true (but unknown) average strike frequency, F_A, we require an estimator $\hat{F}_A$ such that by using available data, we may bound $\hat{F}_A$ as $F_L \le \hat{F}_A \le F_u$ where the probability that F_A lies outside the range (F_L, F_u) is less than any desired percent.

Performing an accurate estimate of F_A from the limited data is made even more difficult because the "population distribution" is unknown. That is, the actual distribution of strike amplitude is unknown and cannot be assumed to be "normal". Thus, special steps must be taken to circumvent this difficulty. One possibility is to utilize non-parametric methods which can be applied to the data without regard to the population distribution. This is easily done, however, non-parametric methods tend to be "inefficient" in that it takes relatively many data points to provide an accurate estimate (i.e., to define a narrow range for the estimated value).

An alternative to the non-parametric methods is to construct a family of distribution curves for strike frequency versus conditions, aircraft type, and flight scenario. A composite cumulative distribution curve may then be determined by using a best fit of the data. Standard techniques may then be applied to this "known" distribution to establish the range for F_A.

This procedure was used on the Navy data [2] to find a best fit chi-square distribution which was, in turn, used to find bounds for F_A. The results are as follows. For an interval which covers 99% of all strikes (i.e., only 1% of the composite distribution curve lies outside the interval), the strike frequency, F_A was found to lie in the range $(9.1 \times 10^{-6}, 2.8 \times 10^{-5})$; this corresponds to a flight hours/ strike (i.e. $1/F_A$) range of (36,000, 110,000). Note that this result is based upon the use of all data "lumped together" and therefore does not distinguish strike frequency versus type of aircraft. From the data available, it was not possible to make separate quantitative estimates for each aircraft type, however, it is clear that the strike frequency for non-patrol aircraft is substantially less. For example, the 99% interval for fighter/attack aircraft appears to be in the range of $(1.3 \times 10^{-5}, 5.9 \times 10^{-6})$ for F_A with a corresponding flight hours per strike of (77,000, 169,000). Regardless of what the exact frequency may be, this data clearly says that the values typically used (~5000 hrs/strike) are too severe.

Similar statistical procedures can be applied to strike amplitude data to determine if the ground based lightning statistics are realistic. Comparisons can be made either for worst case (99th percentile) or for average strikes (or for both). The primary difficulty in this application is the shortage of good flight data. In order to develop reasonable precise estimates (i.e., upper and lower bounds on the estimator which are relatively close), there must be a fairly large data base. This is particularly necessary for the application of non-parametric techniques where the estimators are less efficient because no knowledge of the sample distribution is presumed. Since the only flight data used for this evaluation were from the programs conducted by NASA[3, 4, 5] and the Air Force, precise confidence bounds could not be established. However, for estimation purposes, an approximate value of the average strike amplitude can be calculated from the inflight data. If this average is used in conjunction with a strike amplitude distribution curve whitch fits ground lightning statistics, then a range can be established to include 99% of all strikes. Using this procedure, a value of approximately 6.5 kiloamperes (KA) was found for the average measured strike and the 99% range for strike amplitude was found to be (1.2KA, 65KA).

Since the accuracy of this procedure cannot be determined, it is not clear what weight to give to the results. However, the strong implication is that the inflight lightning threat is less severe than the ground based threat traditionally used for the design of aircraft protection. This agrees with a recent examination of approximately 10 strikes to fighter aircraft radomes which indicated amplitudes of 10 kiloamperes or less.

The significance of these numbers becomes apparent when compared with the typical requirement for tactical aircraft of a 200KA strike every 5,000 flight hours.

The location of strike points on an aircraft should also be considered as a probability situation. A few primary attach points (nose, wing tips, tail trailing edge) are involved in most strikes. Lightning will attach to these primary points when approaching the aircraft from wide solid angles. However, some initial attach points such as inboard pylons may have an attach window of only a few degrees wide by a few degrees long. The probability of striking these locations with a direct attach strike is small. They can be assigned a probability figure based upon the solid angle involved.

An example would be an inboard pylon that tests have shown can only be an attach point from the underneath side of the wing. If, for this inboard pylon, if we assume a solid angle corresponding to a cone of angle ψ (ψ small), the ratio of solid angle to the total sphere is $\frac{\pi\psi^2}{4.4\pi}$. For $\psi = 2$ degrees, (.035 radians), the ratio is $7.6 \times 10^{-5} \doteq .00008$ or, assuming both attach and exit points, the ratio is 0.00016. If we now consider that there is 1 strike every 100,000 flight hours we expect one strike each $\frac{100,000}{0.00016} = 625,000,000$ flight hours to the inboard pylon.

Considering a 1,000 aircraft fleet and an average life of 10,000 flight hours per aircraft there is then only a 1.6% probability that any aircraft in the total fleet life will be struck on that pylon. If it is further assumed that a 20KA strike will cause no damage, then the probability of strike amplitude and strike rate can be combined to provide a probability of damage. From previous paragraphs it could be assumed that there is about a 5% probability (95th percentile) that any strike would exceed 20KA. This yields a probability of damage to the inboard Pylon for all aircraft of 0.05 x 0.016 = 8 x 10^{-4}. In this manner, a probability of damage or risk factor could be defined for each aircraft type and mission. In many cases it may not be advisable to incur a lightning protection penalty for such a low probability of damage.

Swept stroke areas are also affected by improbable, but possible, attach points. By eliminating an attach point based upon a low strike probability, significant aircraft fuselage areas may be exempted from swept stroke protection. Using the inboard pylon as an example, the swept stroke area could include parts of wings and stabilator. This swept stroke area should first be examined to determine if lightning protection is required and if so, what penalties are incurred. Then, a probability of damage should be computed. A trade study of risk versus penalty should then be used to decide if protection is to be applied.

The extensive use of composite materials makes the application of overly stringent requirements exceedingly expensive both in dollars and in aircraft performance. For example, our tests have shown that a typical fastener in a carbon fiber composite (CFC) structure can carry a 25KA lightning strike without strength degradation and that a bonded lap joint can transfer approximately 2KA/in^2 also without damage. Thus, depending upon the magnitude of this lightning strike requirement, protection may or may not be required. Approximately 5 plies of CFC cloth (0.05 inches) is required to withstand the 100KA restrike component presently specified. Many aircraft panels, doors, and fuselage sections can meet all structural requirements if made from thinner material. However, using a thinner material and the 100 KA requirement requires the application of protective coatings or layers. These added layers, of course, present a penalty (cost, weight, maintenance) that tend to negate some of the CFC advantages. If the restrike component were 10KA instead of 100KA, much thinner CFC could be used without a lightning protection penalty.

OTHER INFLUENCES

A significant amount of testing to define lightning strike amplitudes has been done from mountain tops. This data represents a specific geographic area, altitude and terrain. Thus, another probability that may influence the strike amplitude data is variations in the geographical distribution of strikes. It is probable that data gathered from mountain tops located in mid-continent regions may not be valid for aircraft that generally fly over water, coastal regions or deserts. This is an area that warrants future study.

CONCLUSIONS

It is not unusual for commercial and military aircraft to have different specifications. Rather the converse is true and there are probably more environmental and safety specifications that are different than are the same. Thus, to arbitrarily place the same requirement on a fighter aircraft with built-in-tolerance for battle damage and a large commercial passenger aircraft does not seem prudent or cost effective.

The application for tactical military aircraft of more realistic values of lightning strikes and the use of probabilities of occurrence, magnitude and damage would remove many of the penalties associated with lightning protection with only a minimum increase in risk.

RECOMMENDATIONS

- o It is recommended that efforts be increased to gather inflight strike data.
- o The Navy study of strike occurrence should be continued and broadened to include Air Force data and military aircraft data from other countries.
- o A lightning specification should be prepared for military aircraft. Different requirements should be available for various aircraft types and missions.

ACKNOWLEDGEMENT

The assistance of Dr. C. D. Skouby in the preparation of this paper is appreciated.

REFERENCES

[1] Cianos, N. and Pierce, E.T., "A Ground Lightning Environment for Engineering Usage", Technical Report SRI Project 1834, 1972.

[2] Lane, R.F., United States Navy Inservice Aircraft Lightning Strike and Damage Survey, NADC, 1981.

[3] Pitts, F.L., Electromagnetic Measurement of Lightning Strikes to Aircraft, NASA Langley, 1981.

[4] Fisher, B.D.; Keyser Jr., G.L.; Deal, P.L., "Lightning Attachment Patterns and Flight Conditions for Storm Hazards '80".

[5] Private Conversations with Fisher, B.D. Relating to 1981 and 1982 NASA Flight Test Program Data.